Thermal Conductivity of Materials

Fourier's Law applies to all material. However, different materials conduct heat through very different mechanisms:

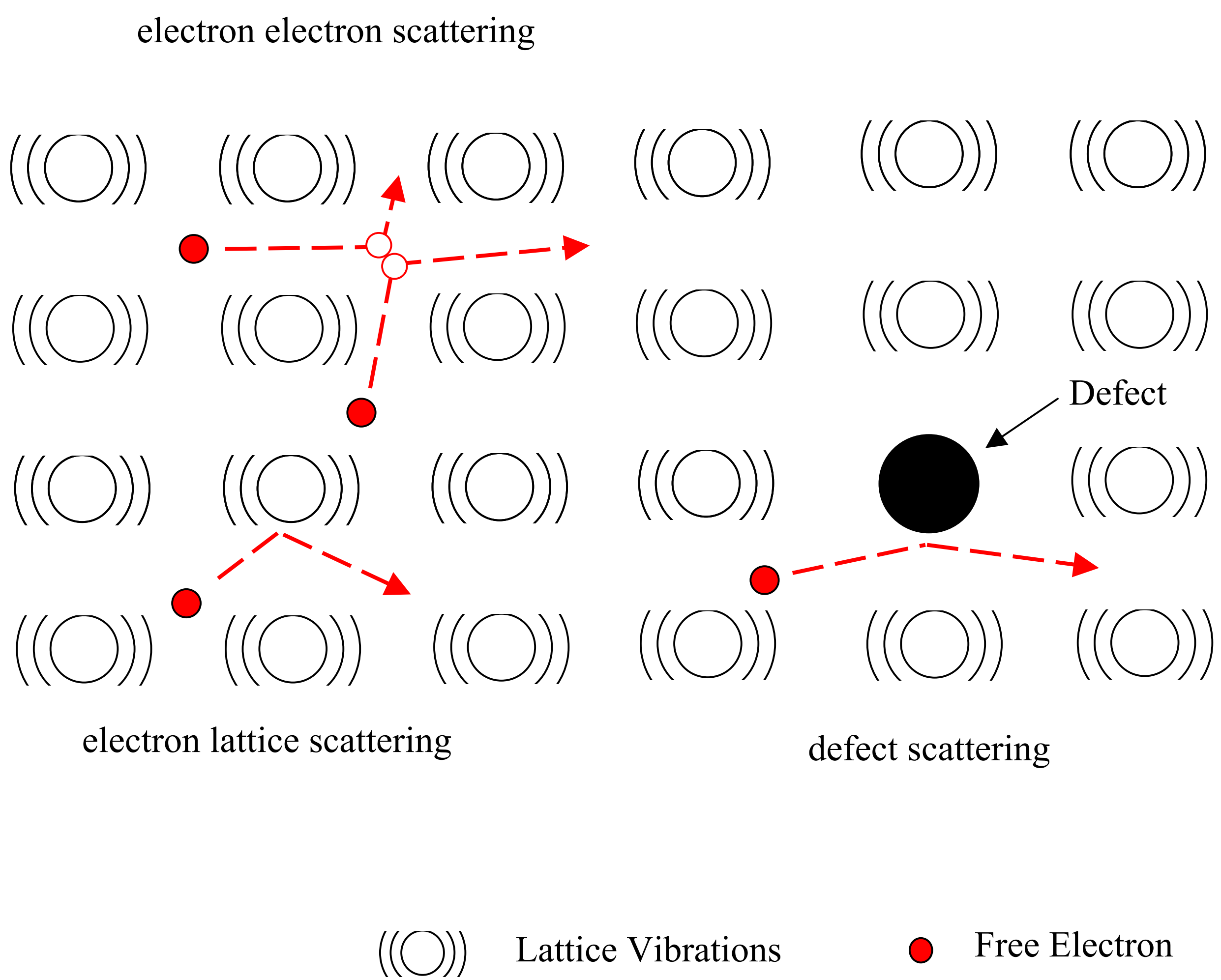
$$q_x'' = -k\frac{dT}{dx}$$

Basic Energy Carriers

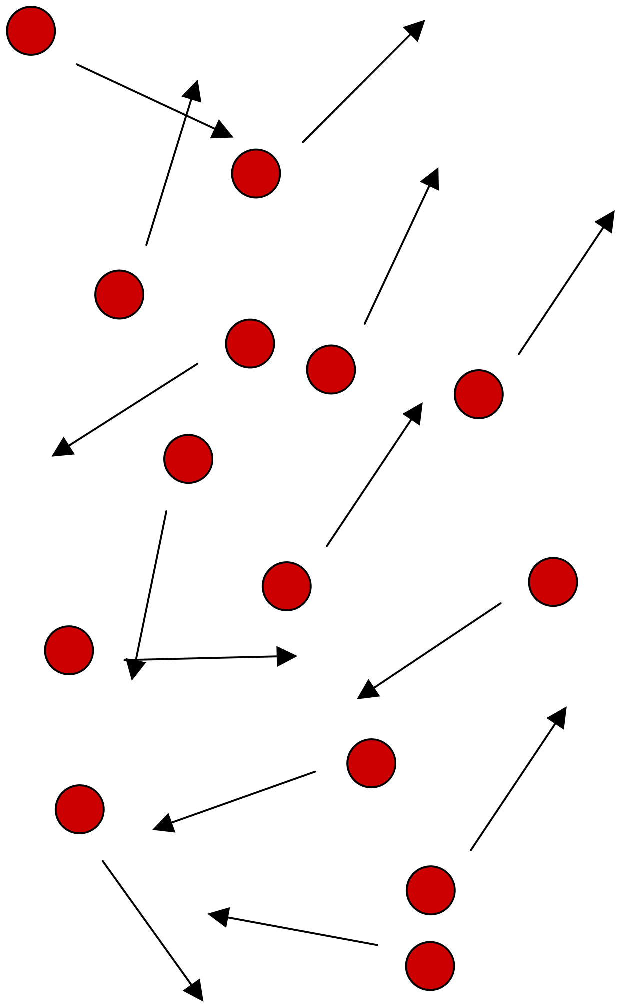
<u>Solids</u>
Metals – **Free Electrons** & Lattice Vibrations
Non-Metals – **Lattice Vibrations (Phonons)**

<u>Liquids and Gases</u>
Individual Molecules

Metals - Free Electrons



Kinetic Theory



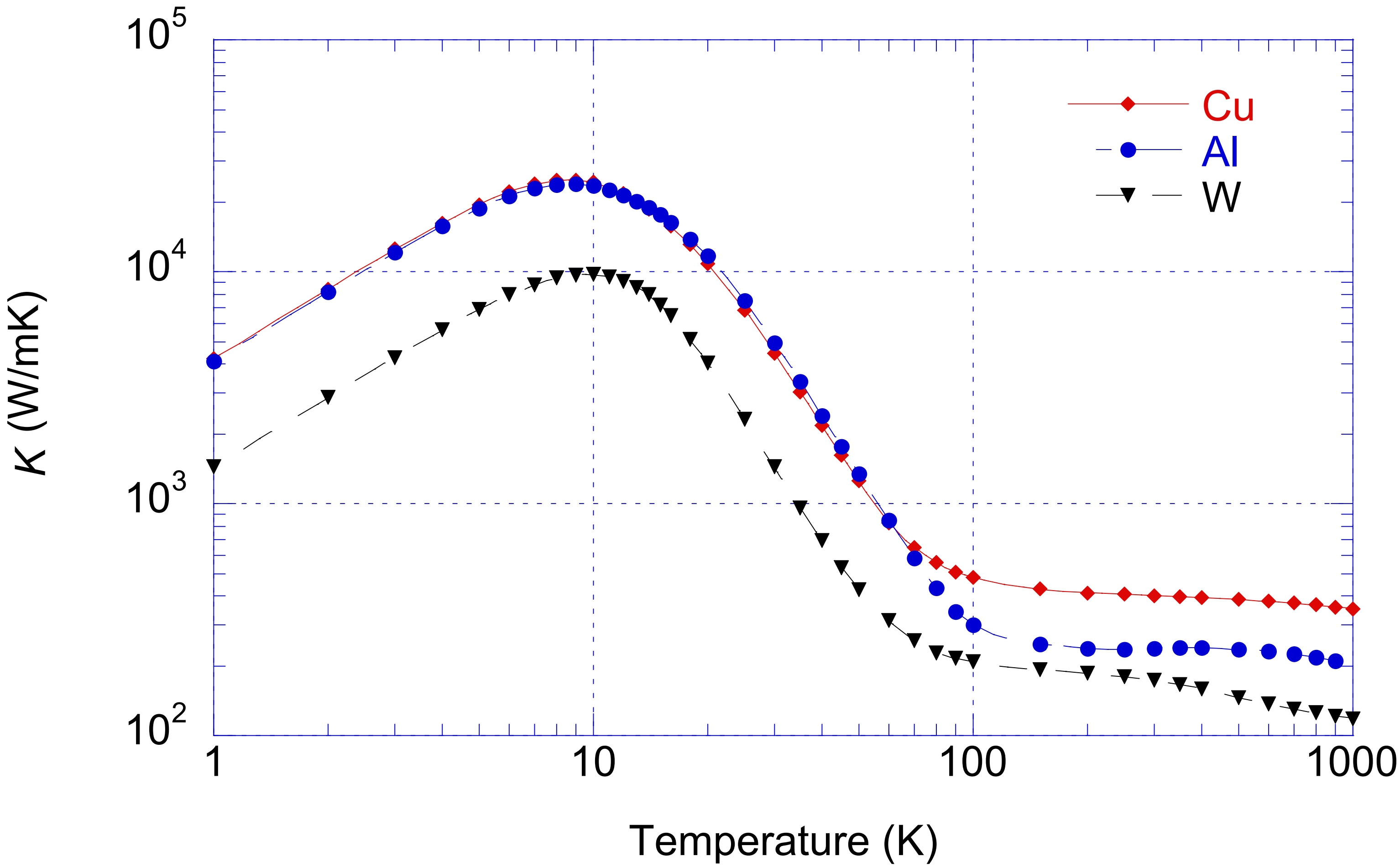
$$k = \frac{1}{3} C V \lambda$$

C – Heat Capacity of Particle
V – velocity of the particle
λ – mean free path

$$\lambda = \frac{V}{v} = \frac{V}{v_D + v_{ee} + v_{el}}$$

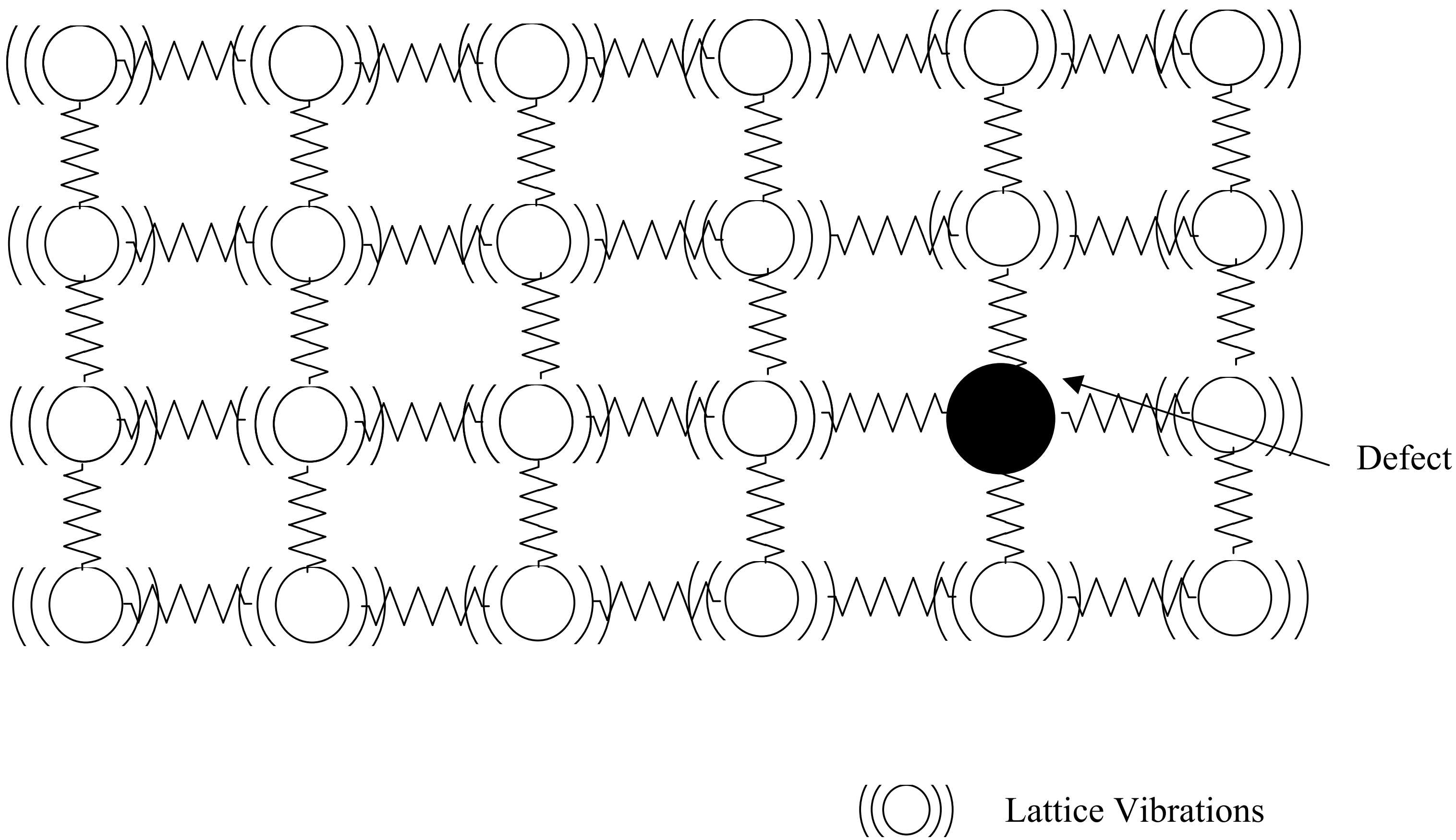
Collisional Frequency- Defect, Electron-Electron, Electron-Lattice

Thermal Conductivity of Metals



Thermal conductivity of Cu, Al, and W plotted as a function of temperature

Lattice Vibrations (Phonon)



Phonon – Lattice Vibration

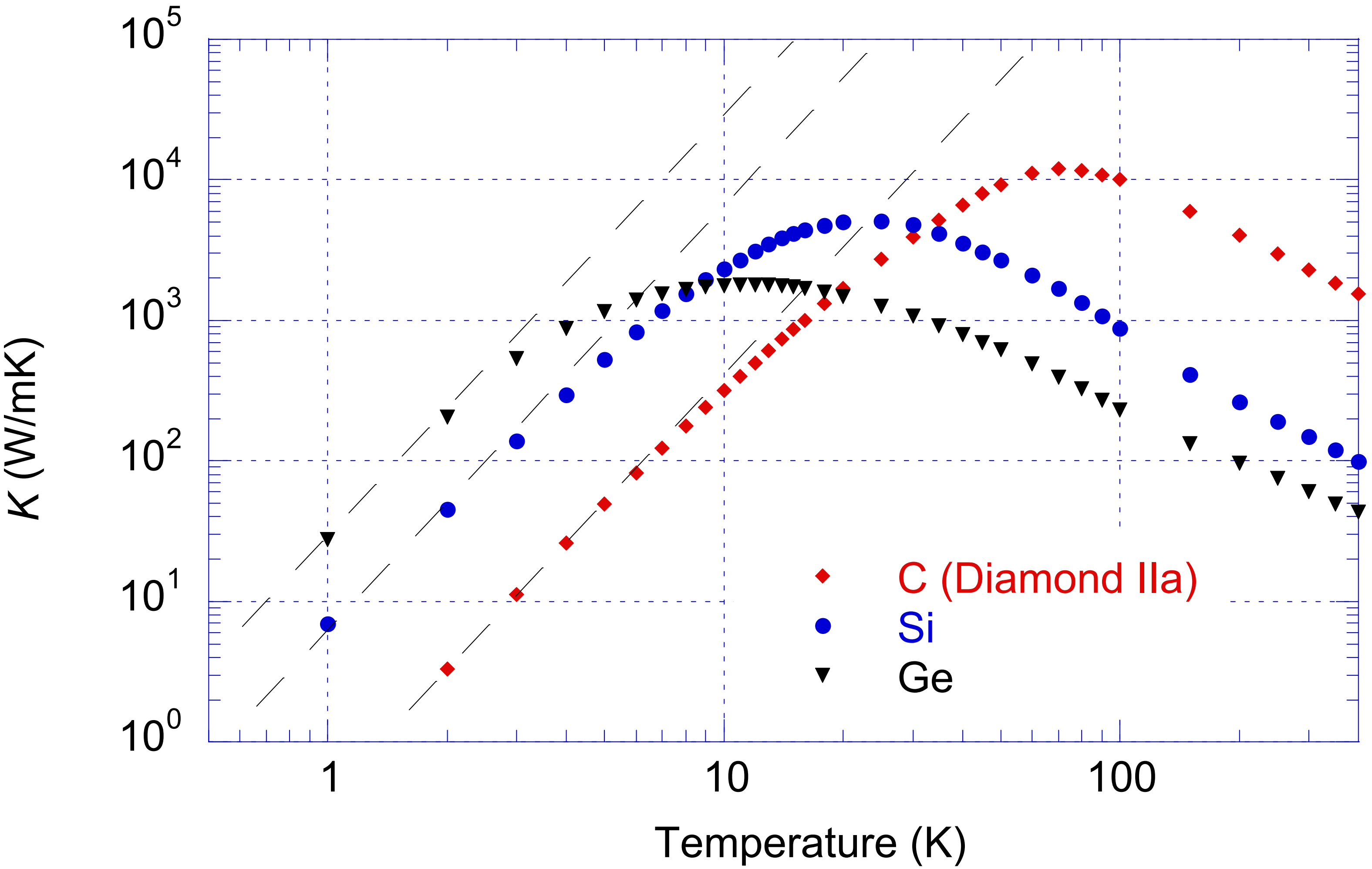
Contains a finite amount of energy that is dependent on the vibrational frequency.

$$k = \frac{1}{3} C V \lambda$$

V = the speed of sound

Therefore, the higher the speed of sound in a solid non-metallic material the better the thermal conductivity

Thermal Conductivity of Diamond



Thermal Conductivity of Solids

$$k = k_e + k_l$$

Summation of the contribution from the electrons and the lattice

Weidemann – Franz Law – ratio of electrical conductivity and thermal conductivity is directly proportional to temperature

$$L = \frac{k}{\sigma T}$$

L – Lorenz Number ~2.45×10^{-8} W-Ω/k^2

Thermal Conductivity of Gases

$$k \propto N\bar{V}\lambda$$

N- Number of Particles per unit Volume
$\bar{V}$ – Velocity
λ – Mean Free Path

Independent of Pressure $$N \propto P \qquad \lambda \propto \frac{1}{P}$$

Increases with Temperature $$T \propto \frac{1}{2}m\bar{V}^2$$